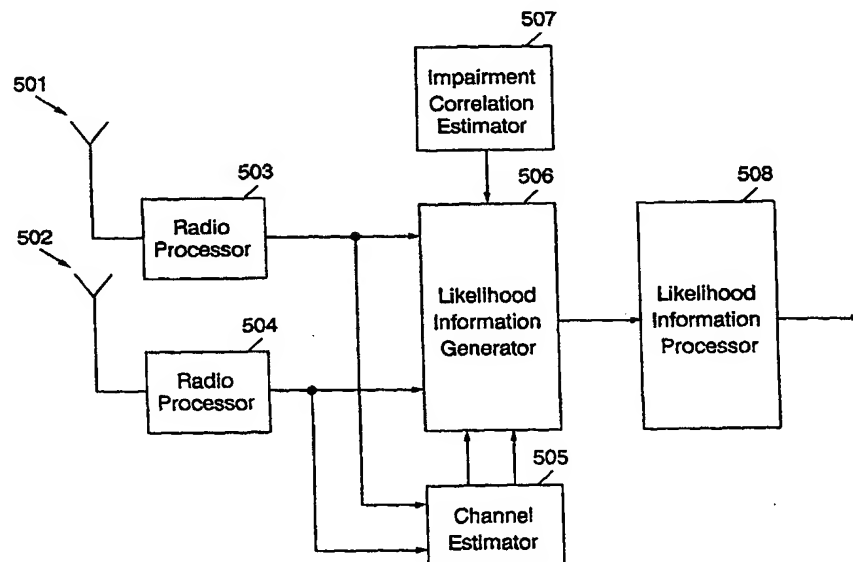




## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>7</sup> : H04L 27/227, 25/03	A1	(11) International Publication Number: WO 00/13386 (43) International Publication Date: 9 March 2000 (09.03.00)
(21) International Application Number: PCT/US99/19221 (22) International Filing Date: 24 August 1999 (24.08.99) (30) Priority Data: 09/143,754 31 August 1998 (31.08.98) US (71) Applicant: ERICSSON, INC. [US/US]; 7001 Development Drive, P.O. Box 13969, Research Triangle Park, NC 27709 (US). (72) Inventors: ARSLAN, Hüseyin; 2400-J Wesville Court, Raleigh, NC 27607 (US). BOTTOMLEY, Gregory, E.; 100 Merlot Court, Cary, NC 27511 (US). RAMÉSH, Rajaram; 403 Danton Drive, Cary, NC 27511 (US). (74) Agents: O'SULLIVAN, Timothy, J. et al.; Myers, Bigel, Sibley & Sajovec, P.A., P.O. Box 37428, Raleigh, NC 27627 (US).		(81) Designated States: AE, AL, AM, AT, AT (Utility model), AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, CZ (Utility model), DE, DE (Utility model), DK, DK (Utility model), EE, EE (Utility model), ES, FI, FI (Utility model), GB, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (Utility model), SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>

(54) Title: COHERENT DEMODULATION AND SEQUENCE ESTIMATION FOR DIFFERENTIAL PSK SIGNALS



## (57) Abstract

Methods and systems are provided which generate hard and soft values from signal samples of a differentially encoded signal by estimating channel coefficients associated with the received signal and determining metrics for each possible symbol pair which indicate the probability of a possible coherent symbol pair being encoded in the signal samples using the estimated channel coefficients and the signal samples. Soft values associated with differential bits or differential symbols encoded in the samples of the signal are then generated based on the determined metrics.

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

## COHERENT DEMODULATION AND SEQUENCE ESTIMATION FOR DIFFERENTIAL PSK SIGNALS

### INFORMATION GENERATION FOR COHERENT DEMODULATION OF DIFFERENTIALLY ENCODED SIGNALS

#### Field of the Invention

The present invention relates generally to radiotelephones and more particularly to the coherent demodulation of differentially encoded quadrature phase shift keying (DQPSK) signals.

#### Background of the Invention

The performance of receivers in wireless radio communications systems may degrade severely due to multipath fading. Although anti-fading techniques, like antenna diversity, equalization, and adaptive array processing, may be very effective in improving the performance of the receiver, forward error correction (FEC) techniques may be necessary to achieve acceptable voice and data transmission in wireless communication systems. FEC techniques provide redundancy by adding extra bits to the actual information bits, which allows the decoder to detect

and correct errors. In the receiver, the decoding process can be performed by either using hard information values or soft information values, which are provided by the demodulator. Decoding using soft  
5 information values improves the receiver performance over decoding using hard information values. Therefore, to improve decoder performance, it may be important to provide accurate soft information from the demodulation process.

10 The U.S. digital cellular system (IS-136) uses  $\pi/4$  shifted-DQPSK as a modulation scheme. Differential encoding of the transmitted signals allows both coherent and differential demodulation of the received signal. Although differential demodulators may  
15 not be complex to implement, it is widely accepted that the performance of differential detectors degrades rapidly in the presence of Inter-Symbol Interference (ISI) which may be caused by multi-path propagation. Therefore, coherent demodulators with equalizers are  
20 commonly used in many receivers. Such a receiver is described in U.S. Patent No. 5,285,480 to Chennakeshu et al., entitled ADAPTIVE MSLE-VA RECEIVER FOR DIGITAL CELLULAR RADIO.

Figure 1 depicts a block diagram of a  $\pi/4$   
25 shifted-DQPSK system with a conventional differential demodulator receiver. The transmitter 105 includes encoder 101 and differential modulator 102. Information bits are encoded in encoder 101 to produce coded bits. The coded bits are differentially modulated in  
30 differential modulator 102 to produce a differentially

modulated signal, which is provided to antenna 104 for transmission. The transmitted signal reaches the radio receiver after passing through a propagation medium (e.g., a mobile radio channel). The transmitted signal  
5 plus any noise are received at the receiver antenna 106 and the received signal provided to receiver 114. The received signal is processed by the radio processor 108 which amplifies, mixes, filters, samples and quantizes the received signal to produce a baseband signal. A  
10 differential demodulator 110 demodulates the received signal and provides symbol or bit values to the decoder 112 which decodes the encoded bits and which may detect and correct possible errors in the received signal. As discussed above, the output of the demodulator 110 is  
15 preferably soft values which may provide higher performance in decoding.

Differential encoding of the transmitted signals allows both coherent and differential demodulation of the received signal. Figure 2 shows a  
20 block diagram of a known apparatus for differential demodulation of the DQPSK modulated signals. The differential detector uses received samples to get hard and/or soft decision values. The present received sample is coupled to the multiplier 203. The present  
25 received sample is also fed into a delay 201. The delay 201 is coupled to a conjugate operator 202, and the output of the conjugate operator 202 is coupled to the multiplier 203.

In operation, the present received sample and  
30 the delayed and conjugated received sample are

multiplied to undo the effect of the differential encoder at the transmitter. The real 204 and imaginary 205 part of the output of the multiplier provide the soft bit values corresponding to the two bits sent in one, di-bit symbol. Also, the hard values can be  
5 obtained by taking the sign 206 and 207 of the soft values as desired.

Figure 3 shows a block diagram of a known apparatus for coherent demodulation of the DQPSK modulated signals. The coherent receiver utilizes  
10 channel estimation unit 302 which estimates the amplitude and phase of the mobile radio channel. These channel estimates are passed to the coherent QPSK demodulator 301 where the estimates of the QPSK symbols  
15 are generated. The channel parameters can be estimated using the known data sequences which are periodically inserted into the transmitted information sequences. In systems where the channel parameters change over the transmission of two consecutive known data sequences,  
20 like the U.S. digital cellular system (IS-136), it is desirable to adapt the channel parameters during the transmission of unknown data sequences. Such an adaptive coherent receiver is described in U.S. Patent No.5,285,480 to Chennakeshu et al. entitled ADAPTIVE  
25 MLSE-VA RECEIVER FOR DIGITAL CELLULAR RADIO.

The output values of the coherent QPSK demodulator 301, which are the hard coherent symbols, are passed through a differential detector 303 to undo the effect of the differential encoder in the  
30 transmitter. The outputs of the differential detector

are the hard decision values corresponding to the transmitted information bits.

A semi-coherent demodulation of the DQPSK modulated signals is described in U.S. Patent No. 5,706,313 to Blasiak et al. entitled SOFT DECISION DIGITAL COMMUNICATION AND METHOD AND APPARATUS in which only the phase and frequency offset are estimated using the received signal. After compensating the phase and frequency offset, the likelihood of each possible QPSK symbol value for each sample is calculated. Therefore, a likelihood vector for each sample is obtained and this likelihood vector is provided to the decoder. The decoder uses the likelihood vectors to estimate the transmitted symbol values.

Another conventional method for the soft decoding of differentially encoded QPSK signal is described in U.S. Patent No. 5,754,600 to Rahnema entitled METHOD AND APPARATUS FOR OPTIMUM SOFT-DECISION VITERBI DECODING OF CONVOLUTIONAL DIFFERENTIAL ENCODED QPSK DATA IN COHERENT DETECTION. In this apparatus the differential and Viterbi decoders are integrated, i.e., differential decoding is part of the convolutional decoding process.

Soft information for maximum likelihood sequence estimation (MLSE) for frequency selective fading channels has been extensively studied, for example as described in J. Hagenauer and P. Hoeher, "A Viterbi algorithm with soft-decision outputs and its applications", *Proceeding of IEEE Globecom Conference*, pp.47.1.1-47.1.7, Dallas, TX, USA, November 1989. These

techniques have been extended to  $\pi/4$  shifted-DQPSK systems for example as described in Jong Park, Stephan B. Wicker and Henry L. Owen, "Soft Output Equalization Techniques for  $\pi/4$  DQPSK Mobile Radio", *IEEE International Conference on Communications*, pp.1503-1507, Dallas, TX, USA, 1997. However, relatively little work has been directed towards soft information generation for coherent detection of  $\pi/4$  shifted-DQPSK in non-ISI channels, i.e. channels without significant inter-symbol interference (ISI). A suboptimal approach is given that requires exponentiation and logarithm operation in Yow-Jong Liu, Mark Wallace and John W. Ketchum, "A Soft-Output Bidirectional Decision Feedback Equalization Technique for TDMA Cellular Radio", *IEEE Journal on selected areas in commun.*, Vol.11, No.7, Sep. 1993. This approach does not consider all possible symbol values in determining a soft value and, further, does not result in a unique solution.

In light of the above discussion, a need exists for improved performance in soft value determination for coherent demodulation of differentially encoded signals for non-ISI channels.

25

#### Summary of the Invention

In view of the above discussion, it is an object of the present invention to provide accurate soft values for differentially encoded information.



A further object of the present invention is to provide soft values in a manner which does not require complex implementation.

Still another object of the present invention  
5 is to provide soft values from coherent detection of differentially encoded bits or symbols.

These and other objects of the present invention are provided by methods and systems which generate soft values from signal samples of a  
10 differentially encoded signal by estimating channel coefficients associated with the signal and determining metrics for each possible combination of current and previous coherent symbol values which indicate the probability of a possible differential bit  
15 value being encoded in the signal using the estimated channel coefficients and the signal samples. Soft values associated with a bit or symbol encoded in the signal are then generated based on the determined metrics.

20 The use of each potential current and previous coherent symbol value in determining a combined metric provides metrics which take into account the probability of each potential symbol value. Thus, by utilizing metrics associated with each  
25 potential symbol value, an accurate soft value may be obtained.

In a further embodiment of the present invention, determining a soft value is done by summing the metrics for each possible current and previous  
30 coherent symbol value that corresponds to a first

differential bit value to provide a first value metric sum and summing the metrics for each possible current and previous symbol value corresponding to a second differential bit value to provide a second value metric sum. The first value metric sum may be divided by the second value metric sum to provide a ratio of probabilities of the differential bit value being the first value and differential bit value being the second value. Further, the metrics may be exponentiated and the exponentiated metrics summed for each possible symbol pair corresponding to a first bit value to provide a first value metric sum. The exponentiated metrics are also summed for each possible symbol pair corresponding to a second bit value to provide a second value metric sum. Also, the logarithm of the ratio of probabilities may be taken to provide the soft value for the bit.

Furthermore, where the differentially encoded signal is received at a plurality of antennas and channel coefficients associated with each of the plurality of antennas are estimated, metrics may be determined for each possible coherent symbol value which indicate the probability of a possible symbol value being encoded in the signal using the estimated channel coefficients and the signal for each antenna. In such a case, each metric is a sum of metrics for each antenna. Also, an impairment correlation may be determined for the plurality of antennas. Metrics may then be determined for each possible symbol value which indicate the probability of a possible coherent symbol

value being encoded in the signal using the estimated channel coefficients, the impairment correlation and the signal for each antenna. A noise power associated with the received signal may be determined and the metrics determined based in part on the noise power.

In a particular embodiment, a detected value is determined from the signal samples and the channel coefficients. The detected values may be bit values for symbols encoded in the differentially encoded signal. Furthermore, the determined soft values may be associated the detected bit values.

Preferably, the signal samples are generated by a radiotelephone receiving and processing a differentially encoded signal.

In another embodiment of the present invention, soft values are generated from signal samples by estimating channel coefficients associated with the received signal and determining metrics for each possible coherent symbol value which indicate the probability of a possible symbol value being encoded in the signal samples of the signal using the estimated channel coefficients and the signal samples of the received signal. The maximum of the combined metrics for each possible current and previous symbol value corresponding to first bit value is determined to provide a first maximum metric value. The maximum metric of the combined metrics for each possible current and previous symbol value corresponding to a second bit value is also determined to provide a second minimum metric value. The second maximum metric value

is then subtracted from the first maximum metric value to provide a difference of log likelihoods of the bit value being the first bit value and the bit value being the second bit value. By selecting the maximum values  
5 the complexity of the soft value determination may be reduced as the exponentiation and logarithm need not be determined.

In still another embodiment of the present invention, soft values are generated from signal  
10 samples by estimating channel coefficients associated with the signal and determining metrics for detected coherent symbol values which indicate the probability of the possible symbol values being encoded in the signal using the estimated channel coefficients and the  
15 signal samples of the signal. A detected term is determined from the metrics associated with the detected symbols which provides a first value metric corresponding to the detected differential bit. A second value metric, which corresponds to the non-  
20 detected bit, is obtained by obtaining the two different metric values by either flipping the current detected coherent symbol value or the previous detected coherent symbol value and keeping the other coherent symbol value as the detected value and selecting the  
25 maximum metric value among these two values. This alternative embodiment may further reduce the complexity of the soft value determination by basing the soft value determination on a detected symbol value.

30

### Brief Description of the Drawings

Figure 1 is a block diagram of a convention  
DQPSK communication system;

Figure 2 is a block diagram of a conventional  
5 system for demodulation of DQPSK signals;

Figure 3 is a block diagram of a conventional  
system for coherent demodulation of DQPSK signals;

Figure 4 is a block diagram of a  
radiotelephone incorporating the present invention;

10 Figure 5 is a block diagram of one embodiment  
of the present invention;

Figure 6 is a block diagram of an alternative  
embodiment of the present invention;

Figure 7 is a block diagram of a second  
15 alternative embodiment of the present invention;

Figure 8 is a flow chart illustrating  
operations of one embodiment of the present invention;

Figure 9 is a flow chart illustrating  
operations of an alternative embodiment of the present  
20 invention; and

Figure 10 is a flowchart illustrating  
operation of the second alternative embodiment of the  
present invention.

### Detailed Description of the Invention

25 The present invention now will be described  
more fully hereinafter with reference to the  
accompanying drawings, in which preferred embodiments  
of the invention are shown. This invention may,  
30 however, be embodied in many different forms and should

not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout. As will be appreciated by one of skill in the art, the present invention may be embodied as methods or devices. Accordingly, the present invention may take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment combining software and hardware aspects.

An embodiment of a radiotelephone 10 which includes a soft value generator 15 according to the present invention is depicted in the block diagram of Figure 4. As shown in Figure 4, radiotelephone 10 typically includes a transmitter 12, a receiver 14, a user interface 16 and an antenna system 18. The antenna system 18 may include an antenna feed structure 22 and an antenna 20. As is well known to those of skill in the art, transmitter 12 converts the information which is to be transmitted by radiotelephone 10 into an electromagnetic signal suitable for radio communications. Receiver 14 demodulates electromagnetic signals which are received by radiotelephone 10 so as to provide the information contained in the signals to user interface 16 in a format which is understandable to the user. A wide variety of transmitters 12, receivers 14, user interfaces 16 (e.g., microphones, keypads, rotary dials) which are suitable for use with handheld

radiotelephones are known to those of skill in the art, and such devices may be implemented in radiotelephone 10. The design of radiotelephone 10 other than the software generator 15 is well known to those of skill in the art and will not be further described herein. Furthermore, as will be appreciated by those of skill in the art, the present invention may be utilized in a base station and such an embodiment of the present invention need not be further described herein.

10               **Figure 5** depicts a coherent demodulator for DQPSK modulated signals incorporating the soft value generator 15 according to the teachings of the present invention. The baseband received signal is coupled to the likelihood information generator 404 and the  
15               channel estimator 402. The output of the channel estimator 402 is coupled to the input of the likelihood information generator 404. The output of the likelihood information generator 404 is coupled to the input of the likelihood information processor 406.

20               In operation, the channel estimator 402 estimates the complex channel coefficient corresponding to the mobile radio channel. In essence, each received sample  $r(k)$  is modeled as:

$$r(k) = c(k)s(k) + n(k) \quad (a)$$

25               where  $c(k)$  is the complex channel coefficient,  $s(k)$  is the coherent QPSK symbol sent, and  $n(k)$  is noise. By contrast, in an equalizer, the channel is modeled with multiple channel taps as:

$$r(k) = c_0(k)s(k) + c_1(k)s(k-1) + n(k) \quad (b)$$

In the present invention, channel estimation refers to estimating a single channel coefficient associated with a received value as shown in the equation (a) above.

The baseband received signal and the channel  
5 estimate are used in likelihood information generator 404 to calculate the likelihood functions corresponding to different QPSK symbol hypotheses.

The likelihood information generator 404 may provide likelihood or log-likelihood functions. The  
10 output of the likelihood information generator 404 is passed to the likelihood information processor 406 to calculate the soft information values corresponding to each bit. The partition of the functions in blocks such as the likelihood information generator 404 and  
15 likelihood information processor 406 can differ from implementation to implementation and, therefore, the present invention should not be limited to the configuration illustrated in Figure 5. Also, blocks 404 and 406 can be combined to obtain a single function  
20 which generates soft information using the channel parameters and the received baseband signal. In the present description, only one partition is described, however, those of skill in the art will recognize other suitable partitions.

25 For the remainder of the description herein, the coherent QPSK symbols are represented with  $a(k)$ , and at the time instance  $k$ , and the differential symbol,  $b(k) = b_R + jb_I(k)$ , is a function of  $\{a(k), a(k-1)\}$ , i.e.,  $b(k) = e^{j\pi/4} a(k) [a(k-1)]^*$ . Real (in-phase) and  
30 imaginary (quadrature-phase) bits of the differential



symbols are represented as  $b_R(k)$  and  $b_I(k)$  respectively. Table 1 summarizes the relation between the phase of  $b(k)$ ,  $\{a(k), a(k-1)\}$ , and the sign of  $b_R(k)$  and  $b_I(k)$  ( $\pm 1$  in value) for DQPSK. For  $\pi/4$ -shift DQPSK,  $b(k) =$   
 5  $a(k)[a(k-1)]^*$  and Table 1 below would be modified accordingly.

Soft information can be obtained by taking the log-likelihood ratio of the probability of the detecting +1 (0) and the probability of the detecting  
 10 -1 (1), given the received signal. For coherent demodulation of multi-channel/multi-antenna signals, the log-likelihood ratio can be written as:

$$LR = \log \left[ \frac{P\{b_i(k) = +1 | r(k), r(k-1)\}}{P\{b_i(k) = -1 | r(k), r(k-1)\}} \right] \quad (1)$$

15

where  $i=R$  or  $I$ ,  $r(k) = [r_1(k) \dots r_N(k)]^T$  is the vector representation of the received signal on  $N$  antennas. As can be seen, each differential bit depends on current and previous received signal values. For  
 20 DQPSK, Equation 1 becomes:

$$LR = \log \left[ \frac{\sum_{x=0}^3 \sum_{y=0}^3 I(+1, x, y, i) P\{a(k) = S_x \& a(k-1) = S_y | r(k), r(k-1)\}}{\sum_{x=0}^3 \sum_{y=0}^3 I(-1, x, y, i) P\{a(k) = S_x \& a(k-1) = S_y | r(k), r(k-1)\}} \right] \quad (2)$$

where  $I \in \{1, 0\}$  is the indicator function whose values  
 25 can be obtained from Table 1, and  $S_x = e^{j\pi/2 + \pi/4}$  and where  $x$  and  $y$  correspond to the 4 possible values for the

symbols corresponding to  $a(k)$  and  $a(k-1)$  respectively. Note that the indicator function is on half the time, so that of the 16 possible combinations, there are 8 that correspond to the numerator and 8 that correspond to the denominator. The terms that correspond to the numerator and the denominator can be obtained using Table 1. As a result, in Equation 2 both numerator and denominator consist of the logarithm of a sum of 8 terms, using the fact that  $\log(a/b) = \log(a) - \log(b)$ .

10 Table 1 Relation between coherent symbols, differential symbols and differential bits

$a(k)$	$a(k-1)$	$b(k)$	$b_r(k)$	$b_I(k)$
$\pi/4$	$\pi/4$	$\pi/4$	+	+
$\pi/4$	$3\pi/4$	$-\pi/4$	+	-
$\pi/4$	$-\pi/4$	$3\pi/4$	-	+
$\pi/4$	$-3\pi/4$	$-3\pi/4$	-	-
$3\pi/4$	$\pi/4$	$3\pi/4$	-	+
$3\pi/4$	$3\pi/4$	$\pi/4$	+	+
$3\pi/4$	$-\pi/4$	$-3\pi/4$	-	-
	$-3\pi/4$	$-\pi/4$	+	-
$-\pi/4$	$\pi/4$	$-\pi/4$	+	-
$-\pi/4$	$3\pi/4$	$-3\pi/4$	-	-
$-\pi/4$	$-\pi/4$	$\pi/4$	+	+
$-\pi/4$	$-3\pi/4$	$3\pi/4$	-	+
$-3\pi/4$	$\pi/4$	$-3\pi/4$	-	-
$-3\pi/4$	$\pi/4$	$3\pi/4$	-	+
$-3\pi/4$	$\pi/4$	$-\pi/4$	+	-
$-3\pi/4$	$-3\pi/4$	$\pi/4$	+	+

Using the Bayes rule, assuming equi-likely bit values, Equation 2 can be re-written as:

$$LR = \log \left[ \frac{\sum_{x=0}^3 \sum_{y=0}^3 I(+1, x, y, i) P\{r(k) | a(k) = S_x\} P\{r(k-1) | a(k-1) = S_y\}}{\sum_{x=0}^3 \sum_{y=0}^3 I(-1, x, y, i) P\{r(k) | a(k) = S_x\} P\{r(k-1) | a(k-1) = S_y\}} \right] \quad (3)$$

Equation 3, which uses coherent QPSK symbol hypotheses, gives the optimal soft information. The probabilities in Equation 3 for multiple receive antennas can be written as:

$$P\{r(k) | a(k) = S_i\} = \frac{1}{\pi^N |R_{nn}(k)|} e^{-\{r(k) - r_h(k)\}^H R_{nn}^{-1}(k) \{r(k) - r_h(k)\}} \quad (4)$$

where  $r_h(k) = c(k) S_i$  is the hypothesis of the received signal and  $R_{nn}$  is the noise or impairment correlation matrix. Substituting the probabilities, Equation 3 can be re-written as seen in Equation 5.

$$LR = \log \left[ \frac{\sum_{x=0}^3 \sum_{y=0}^3 I(+1, x, y, i) \exp\{-(r(k) - r_h(k, S_x))^H R_{nn}^{-1}(k) (r(k) - r_h(k, S_x)) - (r(k-1) - r_h(k-1, S_y))^H R_{nn}^{-1}(k) (r(k-1) - r_h(k-1, S_y))\}}{\sum_{x=0}^3 \sum_{y=0}^3 I(-1, x, y, i) \exp\{-(r(k) - r_h(k, S_x))^H R_{nn}^{-1}(k) (r(k) - r_h(k, S_x)) - (r(k-1) - r_h(k-1, S_y))^H R_{nn}^{-1}(k) (r(k-1) - r_h(k-1, S_y))\}} \right] \quad (5)$$

In equation 5, there are metrics corresponding to coherent symbol log likelihoods of the form:

$$M = -(r(k) - r_h(k, S_x))^H R_{nn}^{-1}(k) (r(k) - r_h(k, S_x)) \quad (5b)$$

For the special case that the noise power is equal on each antenna and the spatial correlation of the noise across different antennas is zero, the above likelihood function becomes:

$$\hat{b}_i^{opt} = \log \left[ \frac{\sum_{x=0}^3 \sum_{y=0}^3 I(+1, x, y, i) \exp \left\{ - \sum_{d=1}^N \frac{|r_d(k) - r_{d,h}(k, S_x)|^2}{2\sigma^2(k)} + \frac{|r_d(k-1) - r_{d,h}(k-1, S_y)|^2}{2\sigma^2(k)} \right\}}{\sum_{x=0}^3 \sum_{y=0}^3 I(-1, x, y, i) \exp \left\{ - \sum_{d=1}^N \frac{|r_d(k) - r_{d,h}(k, S_x)|^2}{2\sigma^2(k)} + \frac{|r_d(k-1) - r_{d,h}(k-1, S_y)|^2}{2\sigma^2(k)} \right\}} \right] \quad (6)$$

where  $\sigma^2$  is the noise power on each antenna. As can be seen, the optimal soft information for multi-  
 5 channel/multi-antenna receivers can be obtained by first combining the metrics on different antennas (predetection combining), followed by soft information generation. Equation 6 can be further simplified as

$$\begin{aligned} \hat{d}_i^{opt} = & \log \left[ \sum_{x=0}^3 \sum_{y=0}^3 I(+1, x, y, i) \exp \left\{ - \sum_{d=1}^N \operatorname{Re} \left\{ \frac{c_d(k)^*}{\sigma^2(k)} S_{d,x}^* r_d(k) \right\} + \operatorname{Re} \left\{ \frac{c_d(k-1)^*}{\sigma^2(k)} S_{d,y}^* r_d(k-1) \right\} \right\} \right] - \\ 10 & \log \left[ \sum_{x=0}^3 \sum_{y=0}^3 I(-1, x, y, i) \exp \left\{ - \sum_{d=1}^N \operatorname{Re} \left\{ \frac{c_d(k)^*}{\sigma^2(k)} S_{d,x}^* r_d(k) \right\} + \operatorname{Re} \left\{ \frac{c_d(k-1)^*}{\sigma^2(k)} S_{d,y}^* r_d(k-1) \right\} \right\} \right] \end{aligned} \quad (7).$$

In Equation 7, the following term appears throughout:

$$M = - \operatorname{Re} \left\{ \frac{c_d(k)^*}{\sigma^2(k)} S_{d,x}^* r_d(k) \right\} \quad (8).$$

15 This term is referred to as a coherent (QPSK) symbol metric corresponding to the log likelihood of a potential or hypothetical coherent symbol. However, the term metric generally refers to a value which  
 20 indicates the probability of a possible symbol value being encoded in the signal samples of the received signal.

One implementation of the soft information generation based on the above expressions using multi-antenna receivers considering both thermal noise and other interference (like co-channel interference) is shown in Figure 6. The transmitted signal plus the impairment (thermal noise + interference) are received at the receiver antennas 501 and 502. The received signals are processed by the radio processors 503 and 504, each of which amplify, mix, filter, sample and quantize to produce a baseband signal for a different antenna. Such radio processing is well known to those of skill in the art, and, therefore, will not be described in detail herein. The channel coefficients are estimated in channel estimator 505 for each signal on different antennas using the baseband signals at the output of the radio processors 503 and 504. Such channel estimation is also well known to those of skill in the art and will not be described further herein.

Impairment correlation among the antennas is estimated in impairment correlation estimator 507 which can operate as described in U.S. Patent No. 5,680,419 to Bottomley entitled METHOD AND APPARATUS FOR INTERFERENCE REJECTION COMBINING IN MULTI-ANTENNA DIGITAL CELLULAR COMMUNICATION SYSTEMS the disclosure of which is incorporated herein by reference as if set forth fully. The baseband signals, channel estimates and impairment correlation estimates are provided to likelihood information generator 506 which computes metrics corresponding to  $P\{r(k) | a(k)=S_x\}$  (see equation 5b). The likelihood information is processed in

likelihood information processor 508 to produce soft and/or hard differential bit or differential symbol values (such as Equation 5).

An alternative embodiment of the present invention for uncorrelated noise on each antenna is shown in Figure 7. The present value of the baseband signal is multiplied 601 with the conjugate 602 of the channel estimate and the result is divided 604 by the value of the noise power estimate 603. The noise power estimate is obtained by using the baseband signal and the channel estimates as is well known to those of skill in the art. Relative noise powers may be used, and noise power estimation may be omitted, if the relative noise powers are known. If the relative noise powers are known to be equal, division by the noise power may be omitted.

The output of the divider is coupled with the metric computer 606 and a delay block 605. The present value and the previous (delayed) values plus the hypothesis of the present and previous coherent symbols are used to compute the metrics as described in Equation 8. The metric values from different antennas are combined as shown in Equation 7 in adder 608. Thus, the blocks of Figure 7 except the adder 608 may be repeated for each antenna. If there is only one antenna, adder 608 may be eliminated. These combined metric values are used to obtain soft bit values for the differential bits in likelihood information processor 406 or 508. The combination of the present

values and previous values results in 16 different metric combinations. Out of these 16 combinations only half results in detection of a +1 value for the differential bit, and the remaining half results in -1.

5 In likelihood information processor 406 or 508 the 8 combinations which provide a +1 bit value are used to obtain the first log term as shown in Equation 7 by first taking the exponential of these terms, then summing them all, and finally taking the logarithm of

10 the sum. In the same way, the second log term is obtained by considering the other 8 terms. Finally, the soft differential bit value is obtained by taking the difference of the two log terms.

Although in the present embodiment the soft

15 information generation for the decoding of the received signal is described, these soft values can also be used to obtain the hard values by taking the sign of the soft values. Also, for the generation of the hard values, the logarithm operation can be avoided by

20 computing the numerator and the denominator and then finding the larger of these two values, which provides the hard decision.

The operation of this first embodiment of the present invention is illustrated in the flow chart of

25 **Figure 8.** As seen in **Figure 8**, the determination of the soft values begins by determining symbol log likelihoods (block 700) which corresponds to calculating the metrics of Equations 5b or 8. These metrics are then combined (block 702) and exponentiated

30 (block 704). The process is repeated for all symbol

pairs (blocks 706 and 708). Once a combined metric has been determined for each hypothetical symbol pair, then the combined metrics corresponding to a potential +1 are summed and the combined metrics corresponding to a potential -1 are summed (block 710). The +1 sum is then divided by the -1 sum and the logarithm of that value taken to provide the soft values (block 712).

As seen from the discussion above, to obtain theoretically optimal soft information involves exponentiation and logarithm operations. Also, the impairment correlation or noise variance needs to be estimated and taken into account in each metric calculation. The computational complexity can be reduced by approximating the sums of exponentials with their largest terms, in both numerator and denominator. Because, for reasonable SNR values, the sums are dominated by the largest terms, hence, the effect of other terms can be neglected. Therefore, in the first alternative approach, the log-likelihoods for all symbol hypotheses are calculated as follows:

$$M(k, x) = \frac{-|r(k) - r_h(k, S_x)|^2}{\sigma_k^2}$$

or

$$M(k, x) = \text{Re} \left\{ \frac{c_k^*}{\sigma_k^2} S_x^* r_k \right\} \quad (9)$$

where  $x \in \{0, 1, 2, 3\}$ . Symbol pair log likelihoods may then be determined as follows:

$$C(k, x, y) = M(k-1, x) + M(k, y) \quad (10)$$

Note that these metrics are the sum of two transmitted symbol log-likelihoods. Using Table 1, the metrics for



the numerator (+1), and denominator (-1) are grouped:  
 $G(k, +1)$  = set of  $C(k, x, y)$  such that the differential  
 bit = +1 and  $G(k, -1)$  = set of  $C(k, x, y)$  such that the  
 differential bit = -1. Each of these sets has 8  
 5 elements. Then, the maximum of each group is  
 determined. The soft information in terms of these  
 maximum metrics can be written as:

$$\hat{b}_i^{sub1}(k) = \max(G(k, +1)) - \max(G(k, -1)) \quad (11)$$

The first alternative approach requires the  
 10 computation of sixteen combined metrics,  $C(k, x, y)$ , at  
 each symbol index  $k$ . In fact, at each symbol index only  
 four coherent metrics are calculated. The sixteen  
 combined metrics are obtained by using the coherent  
 metrics at time  $k$  and  $k-1$  using Equation 10. Note that,  
 15 even if a hard decision is determined, the most likely  
 values for the detected coherent symbols are those  
 which maximizes the coherent metrics at each time  
 index. If the detected differential bit is  $d$ , then  
 finding the maximum from  $G(k, d)$  is the same as the  
 20 summation of the maximum metrics (most likelihood  
 values) which are obtained at the symbol instants  $k$ ,  
 $\max(M(k, S_x))$  and  $k-1$ ,  $\max(M(k-1, S_x))$ . Therefore, in the  
 detected bit term, the 8 combination terms are not  
 required to find the maximum of them. The two QPSK  
 25 symbols may be detected and the metrics associated with  
 the detected values utilized. However, in the non-  
 detected term, the 8 combination terms and their  
 maximum is required in the first alternative approach.

One realization of the first alternative  
 30 approach can be obtained using the same block diagram

as shown in Figure 5. The likelihood information generator provides the symbol metrics corresponding to the present values and the symbol metrics corresponding to the previous values. In the likelihood information processor, the maximum of the 8 terms (which is the combination of the metrics corresponding to the present values and previous values which provide a +1 or -1 for the differential bit value) in the numerator and the denominator are selected. The soft information is obtained by taking the difference of these two maximum values. Therefore, the alternative approach does not require exponentiation and logarithm operations. Moreover, the knowledge of the noise variance is not needed for the calculation of soft information as long as it is constant. However, it can be used if desired, should the noise be dominated by time-varying interference.

The operations of this first alternative embodiment are illustrated in Figure 9. As with the embodiment illustrated in Figure 8, the determination of the soft values begins by determining the log likelihood of a possible symbol pair value for the current and previous symbols (block 800) which corresponds to calculating the metrics of Equations 5b or 8. These metrics are then combined (block 802). If there are more possible symbol pairs, then the process is repeated for the next symbol pair (blocks 806 and 808). Otherwise, when a combined metric has been determined for each hypothetical symbol pair, then the maximum combined metric corresponding to a potential +1

is determined and the maximum combined metric corresponding to a potential -1 is determined (block 810). The -1 maximum combined metric is then subtracted from the +1 maximum combined metric to  
5 provide the soft value (block 812).

In another alternative embodiment of the present invention, using the metric values which are provided by the likelihood information generator, the detected differential bit values are decided by finding  
10 the most likely coherent QPSK symbol values (by finding the coherent symbol which minimizes the symbol metric) for the present and previous values. The sum of the minimum symbol metric values at the present and previous time provides the numerator or the denominator  
15 (depending on the detected bit value) terms. Then, the term corresponding to the non-detected bit value (opposite of the detected bit value) can be obtained by finding the maximum of the 8 terms corresponding to the non-detected bit values.

20 Although in the first alternative approach the best terms for the detected and non-detected values are used, the approach can be generalized by taking the best  $K_1$  terms for the detected values and  $K_2$  terms for the non-detected values.

25 The second alternative embodiment is obtained by further simplification of the previous alternative approach, in which it is assumed that the dominant terms include at least one detected symbol value. Therefore, in the second alternative embodiment the  
30 minimum of the 8 terms for the non-detected case is not

found. Instead, it is assumed that the maximum of the 8 terms includes one of the detected QPSK symbols with high probability. Once the detected symbols are found and the corresponding metrics, the combined metric is  
 5 calculated,  $C_{det} = M(k, S_{det}(k)) + M(k-1, S_{det}(k-1))$ . In the non-detected term, by assuming that the dominating terms will include one of the detected symbols, one of the symbols is fixed as the detected symbol and the other term toggled with the closest border symbol and  
 10 then the corresponding metric sum is found,  $C_{nd1} = M(k, S_{det}(k)) + M_{toggle}(k-1, S_{toggle}(k-1))$ . In the same way, the other symbol is fixed as the detected symbol and the previously fixed symbol toggled with the closest border symbol and the second corresponding metric sum  
 15 found,  $C_{nd2} = M_{toggle}(k, S_{toggle}(k)) + M(k-1, S_{det}(k-1))$ . The maximum of these two metric sums is chosen as the maximum term in the non-detected term,  $C_{nd} = \max\{C_{nd1}, C_{nd2}\}$ . As can be seen, this approach uses a further assumption to further reduce the computational complexity of the  
 20 soft value determination.

If the above approach is generalized to any detected differential bit  $\{+1 \text{ or } -1\}$ , the detected bit,  $b_{i,det}$ , is first determined by using the minimum metrics. Then, the above method is applied as if the detected  
 25 bit is +1. The soft bit value, then, is calculated as:

$$\hat{b}_i^{sub2}(k) = b_{i,det} \{C_{det} - C_{nd}\} \quad (12)$$

where  $b_{i,det} = \pm 1$ .

This approach can be further simplified by observing that  $M_{dec}$  and  $M_{nd}$  will contain a common term. Therefore:

$$\Delta_1 = M_{toggle}(k-1, S_{toggle}(k-1)) - M(k-1, S_{det}(k-1)) \quad (13)$$

$$\Delta_2 = M_{toggle}(k, S_{toggle}(k)) - M(k, S_{det}(k)) \quad (14)$$

then

$$\hat{b}_i^{sub2}(k) = b_{i,det}(\min\{\Delta_1, \Delta_2\}) \quad (15)$$

Alternatively, using the metric values which are provided by the likelihood information generator, the detected differential bit values are decided by finding the most likely coherent symbol values (by finding the coherent symbol which minimizes the metric) for the present and previous values. The sum of the maximum metric values at the present and previous time provides the numerator or the denominator (depending on the detected bit value) terms. For the non-detected term, by assuming that the dominating terms will include one of the detected symbols, one of the symbols is fixed as the detected coherent symbol and the other term toggled with the closest border symbol.

The second alternative embodiment of the present invention is illustrated in Figure 10. As seen in Figure 10, the detected symbols are determined and their corresponding metrics (block 900). Then the detected combined metric is determined by summing the maximum metric of the detected symbols (block 902). A first potential non-detected combined metric is determined (block 904) and a second potential non-detected combined metric is also determined (block

906). The maximum of these non-detected combined metrics is selected (block 908) and the soft value determined based on the selected non-detected combined metric and the detected combined metric (block 910).

5 While an example of multiple receive antennas was given, the present invention is applicable to any single and multichannel receiver. The multiple channels could correspond to antennas in an antenna array, such as a phased array or diversity array, possibly with  
10 different polarizations. The multiple channels could also correspond to multiple beams or multiple carriers or multiple codes or multiple time slots.

The present invention can also be used to produce soft information on differential symbols (di-  
15 bits). Instead of a likelihood ratio, likelihoods for each of the different symbol values would be produced. For example, for DQPSK, four soft values would be produced, one for each possible differential symbol value. For the optimal approach, the log likelihood of  
20 a differential symbol value would be the sum of four terms, i.e.

$$LL(S_{diff}) = \log[P\{b(k) = S_{diff} | r(k), r(k-1)\}] \quad (16)$$

$$LL(S_{diff}) = \log \left[ \sum_{x=0}^3 \sum_{y=0}^3 J(S_{diff}, x, y) P\{a(k) = S_x \& a(k-1) = S_y | r(k), r(k-1)\} \right] \quad (17)$$

25

With the first alternative approach, only the largest of the four terms would be used, or its likelihood. For the second alternative approach, the

symbol likelihood would include one of the detected symbol terms.

It will be apparent to one of skill in the art in light of the present disclosure that, by  
5 negating the symbol likelihood metric, and maximization operation should be replaced with the minimization operation. Accordingly, the terms maximize and minimize can be replaced by the term extremize, which means taking the maximum or minimum depending on how the  
10 metrics are defined.

While the present invention has been described with respect to DQPSK, the present invention is applicable to any form of differential encoding, including M'ary DPSK (DQPSK corresponds to  $M=4$ ),  
15 differential amplitude encoding or a combination of the two. In addition, the present invention is applicable to a mixture of differential and normal encoding, providing soft information or detected values to the differentially encoded bits or symbols. In essence,  
20 coherent symbol pairs are hypothesized and symbol pair (combined) metrics are produced. Combinations corresponding to one differential bit value are grouped as are combinations corresponding to the other differential bit value. The likelihood ratio or an  
25 approximation to it are then determined.

The present invention has been described with respect to Figures 8 through 10 which are flowchart illustrations of embodiments of the present invention. It will be understood that each block of the flowchart  
30 illustrations, and combinations of blocks in the

flowchart illustrations, can be implemented by computer program instructions. These program instructions may be provided to a processor to produce a machine, such that the instructions which execute on the processor  
5 create means for implementing the functions specified in the flowchart block or blocks. The computer program instructions may be executed by a processor to cause a series of operational steps to be performed by the processor to produce a computer implemented process  
10 such that the instructions which execute on the processor provide steps for implementing the functions specified in the flowchart block or blocks.

Accordingly, blocks of the flowchart illustrations support combinations of means for  
15 performing the specified functions and combinations of steps for performing the specified functions. It will also be understood that each block of the flowchart illustrations, and combinations of blocks in the flowchart illustrations, can be implemented by special  
20 purpose hardware-based systems which perform the specified functions or steps, or combinations of special purpose hardware and computer instructions.

In the drawings and specification, there have been disclosed typical preferred embodiments of the  
25 invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.



## THAT WHICH IS CLAIMED IS:

1. A method of generating differential values from signal samples of a differentially encoded received signal, the method comprising:
  - estimating channel coefficients associated  
5 with the received signal;
  - determining metrics for each possible coherent symbol pair which indicate the probability of a possible coherent symbol pair being encoded in the received signal using the estimated channel  
10 coefficients and the signal samples of the received signal; and
  - determining differential values associated with information differentially encoded in the received signal based on the determined metrics.
2. A method according to Claim 1, wherein the step of determining differential values comprises the steps of:
  - exponentiating the metrics to form processed  
5 metrics corresponding to all possible pairs of symbol values;
  - summing the processed metrics corresponding to a first differential bit value to provide a first value metric sum; and
  - 10 summing the processed metrics corresponding to a second differential bit value to provide a second value metric sum.

3. A method according to Claim 2, further comprising dividing the first value metric sum by the second value metric sum to provide a ratio of probabilities of the bit value being the first value  
5 and bit value being the second value.

4. A method according to Claim 3, further comprising the step of determining the log of the ratio of probabilities to provide a soft bit value.

5. A method according to Claim 3, further comprising the step of comparing the first metric sum and the second metric sum to determine a hard bit value.

6. A method according to Claim 1, wherein the differentially encoded received signal is received at a plurality of antennas and wherein said step of estimating channel coefficients associated with the  
5 differentially encoded signal comprises estimating channel coefficients associated with each of the plurality of antennas; and

said step of determining metrics for each possible symbol pair comprises the step of determining  
10 metrics for each possible symbol pair which indicate the probability of a possible symbol pair being encoded in the signal samples of the received signal using the estimated channel coefficients and the signal samples of the received signal for at least one antenna.

7. A method according to Claim 6, further comprising the step of summing the metrics for each antenna.

8. A method according to Claim 6, further comprising the step of:

determining an impairment correlation estimate for the plurality of antennas; and

5            wherein said step of determining metrics comprises the step of determining metrics for each possible symbol pair which indicate the probability of a possible symbol pair being encoded in the signal samples of the received signal using the estimated  
10       channel coefficients, the impairment correlation estimate and the received signal samples of at least one antenna.

9. A method according to Claim 1, wherein the differential values correspond to differential bit values.

10. A method according to Claim 9, wherein the differential bit values are soft bit values.

11. A method according to Claim 9, wherein the differential bit values are hard bit values.

12. A method according to Claim 1, wherein the differential values correspond to differential symbol values.

13. A method according to Claim 12, wherein the differential symbol values are soft symbol values.

14. A method according to Claim 12, wherein the differential symbol values are hard symbol values.

15. A method according to Claim 1, further comprising the step of:

determining a noise power associated with the received signal; and

5            wherein said step of determining metrics, comprises the step of determining metrics for each possible symbol pair which indicate the probability of a possible symbol pair being encoded in the signal samples of the received signal using the estimated  
10 channel coefficients, the noise power and the received signal samples.

16. A method according to Claim 1, wherein the received signal samples are generated by a radiotelephone receiving and processing a received signal.

17. A method according to Claim 1, wherein the step of determining metrics comprises the step of:

determining symbol metrics for each possible coherent symbol value which indicate the probability of  
5 a possible coherent symbol value using the estimated channel coefficients and the signal samples; and

summing pairs of symbol metrics to determine metrics for each possible coherent symbol pair.

18. A method of generating differential values from signal samples of a differentially encoded received signal, the method comprising:

- 5     estimating channel coefficients associated with the received signal;
- determining metrics for each possible pair of coherent symbol values which indicate the probability of a possible symbol pair being encoded in the signal samples of the received signal using the estimated
- 10    channel coefficients and the signal samples;
- determining the extremum metrics of the metrics for each possible symbol pair corresponding to a differential values to provided extremum metrics; and
- determining a differential value based on the
- 15    extremum metrics.

19. A method according to Claim 18, wherein the differentially encoded signal is received at a plurality of antennas and wherein said step of estimating channel coefficients associated with the
- 5    received signal comprises estimating channel coefficients associated with each of the plurality of antennas; and

- said step of determining metrics for each possible symbol pair comprises the step of determining
- 10   metrics for each possible symbol pair which indicate the probability of a possible symbol pair being encoded in the signal samples of the received signal using the estimated channel coefficients and the signal samples of at least one antenna.

20. A method according to Claim 19, further comprising the step of summing the metrics for each antenna.

21. A method according to Claim 19, further comprising the step of:

determining an impairment correlation estimate for the plurality of antennas; and

5            wherein said step of determining metrics comprises the step of determining metrics for each possible symbol pair which indicate the probability of a possible symbol pair being encoded in the signal samples of the received signal using the estimated  
10       channel coefficients, the impairment correlation estimate and the signal samples for at least one antenna.

22. A method according to Claim 18, wherein the differential values are differential bit values.

23. A method according to Claim 22, wherein the differential bit values are soft bit values.

24. A method according to Claim 22, wherein the differential bit values are hard bit values.

25. A method according to Claim 18, wherein the differential values correspond to differential symbol values.

26. A method according to Claim 25, wherein the differential symbol values are soft symbol values.

27. A method according to Claim 25, wherein the differential symbol values are hard symbol values.

28. A method according to Claim 18, further comprising the step of:

determining a noise power associated with the received signal; and

5                wherein said step of determining metrics, comprises the step of determining metrics for each possible symbol pair which indicate the probability of a possible symbol pair being encoded in the signal samples of the received signal using the estimated  
10 channel coefficients, the noise power and the signal samples.

29. A method of generating differential values from signal samples of a differentially encoded received signal, the method comprising:

              estimating channel coefficients associated  
5 with the received signal;

              determining detected coherent symbol values based on the received signal samples and the channel coefficients;

              determining a detected metric based on  
10 detected symbol values corresponding to a first and a second symbol period, the received samples and the channel coefficients;

              determining a first potential non-detected metric based on a detected symbol corresponding to the  
15 first symbol period, the received samples and the channel coefficients;

determining a second potential non-detected metric based on a detected symbol corresponding to the second symbol period, the received samples and the channel coefficients;

determining a selected non-detected metric using the extremum of the first and second potential non-detected metrics; and

determining at least one differential value based on the detected metric and the selected non-detected metric.

30. A method according to Claim 29, wherein the differentially encoded signal is received at a plurality of antennas and wherein said step of estimating channel coefficients associated with the received signal comprises estimating channel coefficients associated with each of the plurality of antennas; and

said step of determining metrics for a detected symbol comprises the step of determining a detected metric based on detected symbol values corresponding to a first and a second symbol period, the received samples and the channel coefficients associated with at least one of the antennas.

31. A method according to Claim 30, further comprising the step of:

determining an impairment correlation estimate for the plurality of antennas; and

wherein said step of determining a detected metric comprises the step of determining a detected metric based on detected symbol values corresponding to



a first and a second symbol period, the received samples, the channel coefficients and the impairment correlation estimate.

32. A method according to Claim 29, wherein the differential values are differential bit values.

33. A method according to Claim 32, wherein the differential bit values are soft bit values.

34. A method according to Claim 32, wherein the differential bit values are hard bit values.

35. A method according to Claim 29, wherein the differential values correspond to differential symbol values.

36. A method according to Claim 35, wherein the differential symbol values are soft symbol values.

37. A method according to Claim 35, wherein the differential symbol values are hard symbol values.

38. A method according to Claim 29, further comprising the step of:

determining a noise power associated with the received signal; and

5 wherein said step of determining a detected metric comprises the step of determining a detected metric based on detected symbol values corresponding to a first and a second symbol period, the received samples, the channel coefficients and the noise power.

39. An apparatus for generating differential values from signal samples of a differentially encoded received signal, comprising:

- 5 means for estimating channel coefficients associated with the received signal;
- means for determining metrics for each possible coherent symbol pair which indicate the probability of a possible coherent symbol pair being encoded in the received signal using the estimated
- 10 channel coefficients and the signal samples of the received signal; and
- means for determining differential values associated with information differentially encoded in the received signal based on the determined metrics.

40. An apparatus according to Claim 39, wherein the means for determining differential values comprises:

- 5 means for exponentiating the metrics to form processed metrics corresponding to all possible pairs of symbol values;
- means for summing the processed metrics corresponding to a first differential bit value to provide a first value metric sum; and
- 10 means for summing the processed metrics corresponding to a second differential bit value to provide a second value metric sum.

41. An apparatus according to Claim 40, further comprising means for dividing the first value metric sum by the second value metric sum to provide a

ratio of probabilities of the bit value being the first  
5 value and bit value being the second value.

42. An apparatus according to Claim 41,  
further comprising means for determining the log of the  
ratio of probabilities to provide a soft bit value.

43. A method according to Claim 41, further  
comprising the step of comparing the first metric sum  
and the second metric sum to determine a hard bit  
5 value.

44. An apparatus according to Claim 39,  
wherein the differentially encoded received signal is  
received at a plurality of antennas and wherein said  
means for estimating channel coefficients associated  
5 with the differentially encoded signal comprises means  
for estimating channel coefficients associated with  
each of the plurality of antennas; and

said means for determining metrics for each  
possible symbol pair comprises means for determining  
10 metrics for each possible symbol pair which indicate  
the probability of a possible symbol pair being encoded  
in the signal samples of the received signal using the  
estimated channel coefficients and the signal samples  
of the received signal for at least one antenna.

45. An apparatus according to Claim 44,  
further comprising means for summing the metrics for  
each antenna.

46. An apparatus according to Claim 44,  
further comprising:

means for determining an impairment  
correlation estimate for the plurality of antennas; and  
5 wherein said means for determining metrics  
comprises means for determining metrics for each  
possible symbol pair which indicate the probability of  
a possible symbol pair being encoded in the signal  
samples of the received signal using the estimated  
10 channel coefficients, the impairment correlation  
estimate and the received signal samples of at least  
one antenna.

47. An apparatus according to Claim 39,  
wherein the differential values correspond to  
differential bit values.

48. An apparatus according to Claim 47,  
wherein the differential bit values are soft bit  
values.

49. An apparatus according to Claim 47,  
wherein the differential bit values are hard bit  
values.

50. An apparatus according to Claim 39,  
wherein the differential values correspond to  
differential symbol values.

51. An apparatus according to Claim 50,  
wherein the differential symbol values are soft symbol  
values.

52. An apparatus according to Claim 50,  
wherein the differential symbol values are hard symbol  
values.

53. An apparatus according to Claim 39,  
further comprising:

means for determining a noise power  
associated with the received signal; and

5        wherein said means for determining metrics,  
comprises means for determining metrics for each  
possible symbol pair which indicate the probability of  
a possible symbol pair being encoded in the signal  
samples of the received signal using the estimated  
10    channel coefficients, the noise power and the received  
signal samples.

54. An apparatus according to Claim 39,  
wherein the received signal samples are generated by a  
radiotelephone receiving and processing a received  
signal.

55. An apparatus according to Claim 39,  
wherein the means for determining metrics comprises:

means for determining symbol metrics for each  
possible coherent symbol value which indicate the  
5    probability of a possible coherent symbol value using  
the estimated channel coefficients and the signal  
samples; and

means for summing pairs of symbol metrics to  
determine metrics for each possible coherent symbol  
10    pair.

56. An apparatus for generating differential values from signal samples of a differentially encoded received signal, comprising:

- means for estimating channel coefficients  
5 associated with the received signal;
- means for determining metrics for each possible pairs of coherent symbol values which indicate the probability of a possible symbol pair being encoded in the signal samples of the received signal using the  
10 estimated channel coefficients and the signal samples;
- means for determining the extremum metrics of the metrics for each possible symbol pair corresponding to a differential values to provided extremum metrics; and
- 15 means for determining a differential value based on the extremum metrics.

57. An apparatus according to Claim 56, wherein the differentially encoded signal is received at a plurality of antennas and wherein said means for estimating channel coefficients associated with the  
5 received signal comprises means for estimating channel coefficients associated with each of the plurality of antennas; and

- said means for determining metrics for each possible symbol pair comprises means for determining  
10 metrics for each possible symbol pair which indicate the probability of a possible symbol pair being encoded in the signal samples of the received signal using the estimated channel coefficients and the signal samples of at least one antenna.

58. An apparatus according to Claim 57, wherein further comprising means for summing the metrics for each antenna.

59. An apparatus according to Claim 57, further comprising:

means for determining an impairment correlation estimate for the plurality of antennas; and

5 wherein said means for determining metrics comprises means for determining metrics for each possible symbol pair which indicate the probability of a possible symbol pair being encoded in the signal samples of the received signal using the estimated  
10 channel coefficients, the impairment correlation estimate and the signal samples for at least one antenna.

60. An apparatus according to Claim 56, wherein the differential values are differential bit values.

61. An apparatus according to Claim 60, wherein the differential bit values are soft bit values.

62. An apparatus according to Claim 60, wherein the differential bit values are hard bit values.

63. An apparatus according to Claim 56, wherein the differential values correspond to differential symbol values.

64. An apparatus according to Claim 63, wherein the differential symbol values are soft symbol values.

65. An apparatus according to Claim 63, wherein the differential symbol values are hard symbol values.

66. An apparatus according to Claim 56, further comprising:

means for determining a noise power associated with the received signal; and

5            wherein said means for determining metrics, comprises means for determining metrics for each possible symbol pair which indicate the probability of a possible symbol pair being encoded in the signal samples of the received signal using the estimated  
10 channel coefficients, the noise power and the signal samples.

67. An apparatus for generating differential values from signal samples of a differentially encoded received signal, comprising:

5            means for estimating channel coefficients associated with the received signal;

            means for determining detected coherent symbol values based on the received signal samples and the channel coefficients;

10           means for determining a detected metric based on detected symbol values corresponding to a first and a second symbol period, the received samples and the channel coefficients;



means for determining a first potential non-detected metric based on a detected symbol  
15 corresponding to the first symbol period, the received samples and the channel coefficients;

means for determining a second potential non-detected metric based on a detected symbol  
corresponding to the second symbol period, the received  
20 samples and the channel coefficients;

means for determining a selected non-detected metric using the extremum of the first and second potential non-detected metrics; and

means for determining at least one  
25 differential value based on the detected metric and the selected non-detected metric.

68. An apparatus according to Claim 67, wherein the differentially encoded signal is received at a plurality of antennas and wherein said means for estimating channel coefficients associated with the  
5 received signal comprises means for estimating channel coefficients associated with each of the plurality of antennas; and

said means for determining metrics for a detected symbol comprises means for determining a  
10 detected metric based on detected symbol values corresponding to a first and a second symbol period, the received samples and the channel coefficients associated with at least one of the antennas.

69. An apparatus according to Claim 68, further comprising:

means for determining an impairment correlation estimate for the plurality of antennas; and  
5 wherein said means for determining a detected metric comprises means for determining a detected metric based on detected symbol values corresponding to a first and a second symbol period, the received samples, the channel coefficients and the impairment  
10 correlation estimate.

70. An apparatus according to Claim 67, wherein the differential values are differential bit values.

71. An apparatus according to Claim 70, wherein the differential bit values are soft bit values.

72. An apparatus according to Claim 70, wherein the differential bit values are hard bit values.

73. An apparatus according to Claim 67, wherein the differential values correspond to differential symbol values.

74. An apparatus according to Claim 73, wherein the differential symbol values are soft symbol values.

75. An apparatus according to Claim 73, wherein the differential symbol values are hard symbol values.

76. An apparatus according to Claim 67,  
further comprising the step of:

means for determining a noise power  
associated with the received signal; and

5        wherein said means for determining a detected  
metric comprises means for determining a detected  
metric based on detected symbol values corresponding to  
a first and a second symbol period, the received  
samples, the channel coefficients and the noise power.

77. A method of generating differential  
values from signal samples of a differentially encoded  
received signal, the method comprising:

estimating channel coefficients associated  
5        with the received signal;

determining detected coherent symbol metrics  
corresponding to a first and second symbol period based  
on signal samples of the received signal and the  
channel coefficients;

10        determining toggled coherent symbol metrics  
corresponding to a first and second symbol period based  
on signal samples of the received signal and the  
channel coefficients; and

determining at least one differential value  
15        based on the detected coherent symbol metrics and the  
toggled coherent symbol metrics.

78. An apparatus for generating differential  
values from signal samples of a differentially encoded  
received signal, comprising:

means for estimating channel coefficients  
5 associated with the received signal;  
means for determining detected coherent  
symbol metrics corresponding to a first and second  
symbol period based on signal samples of the received  
signal and the channel coefficients;  
10 means for determining toggled coherent symbol  
metrics corresponding to a first and second symbol  
period based on signal samples of the received signal  
and the channel coefficients; and  
means for determining at least on  
15 differential value based on the detected coherent  
symbol metrics and the toggled coherent symbol metrics.

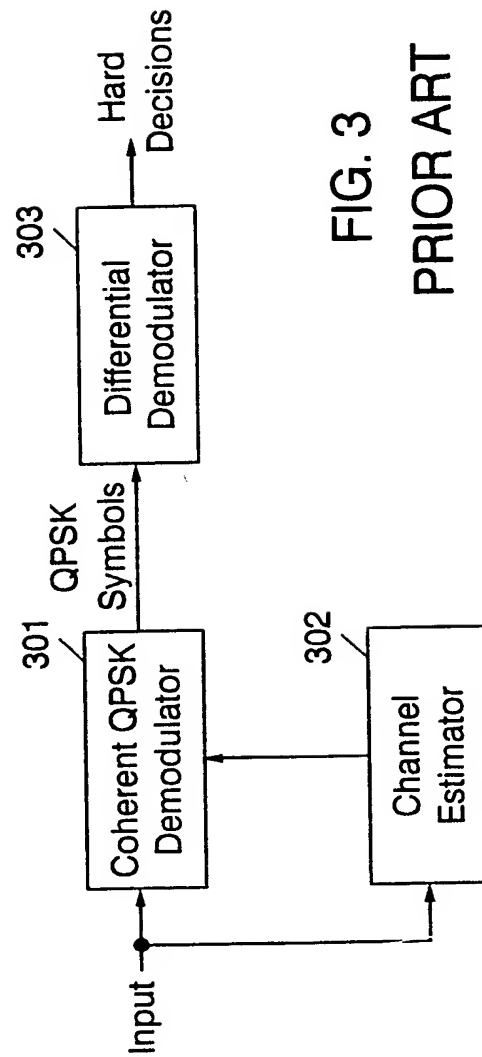
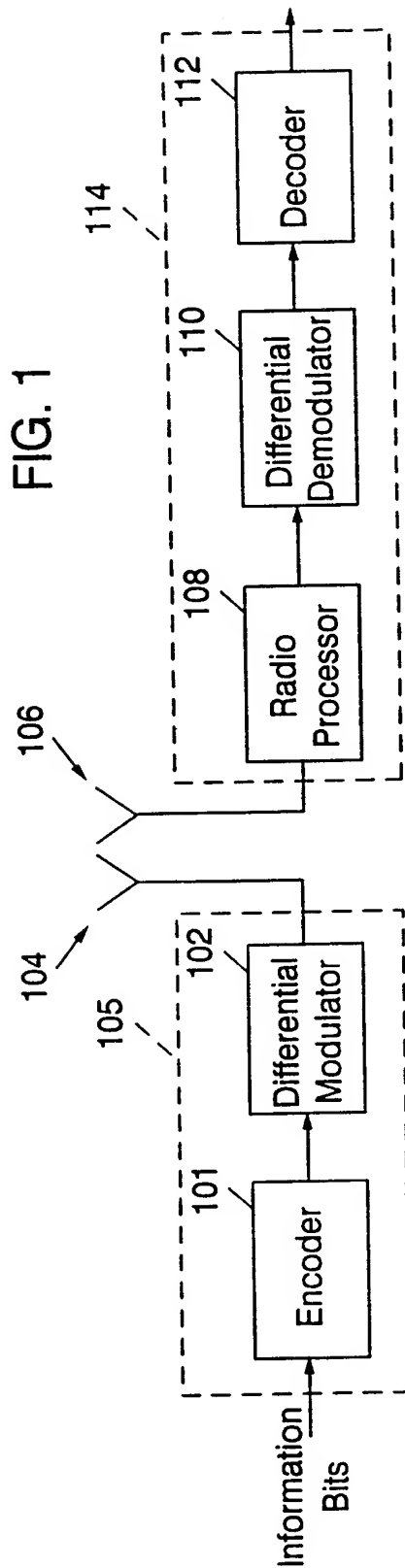


FIG. 2  
PRIOR ART

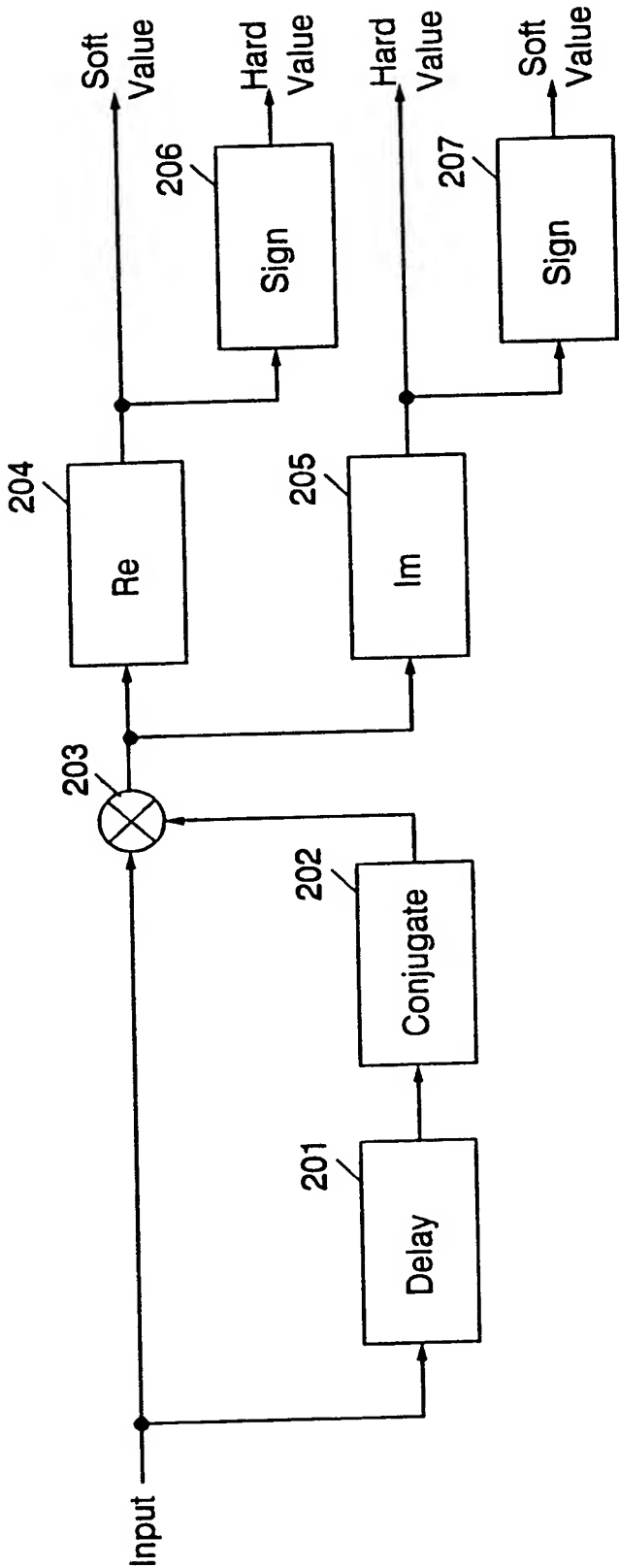
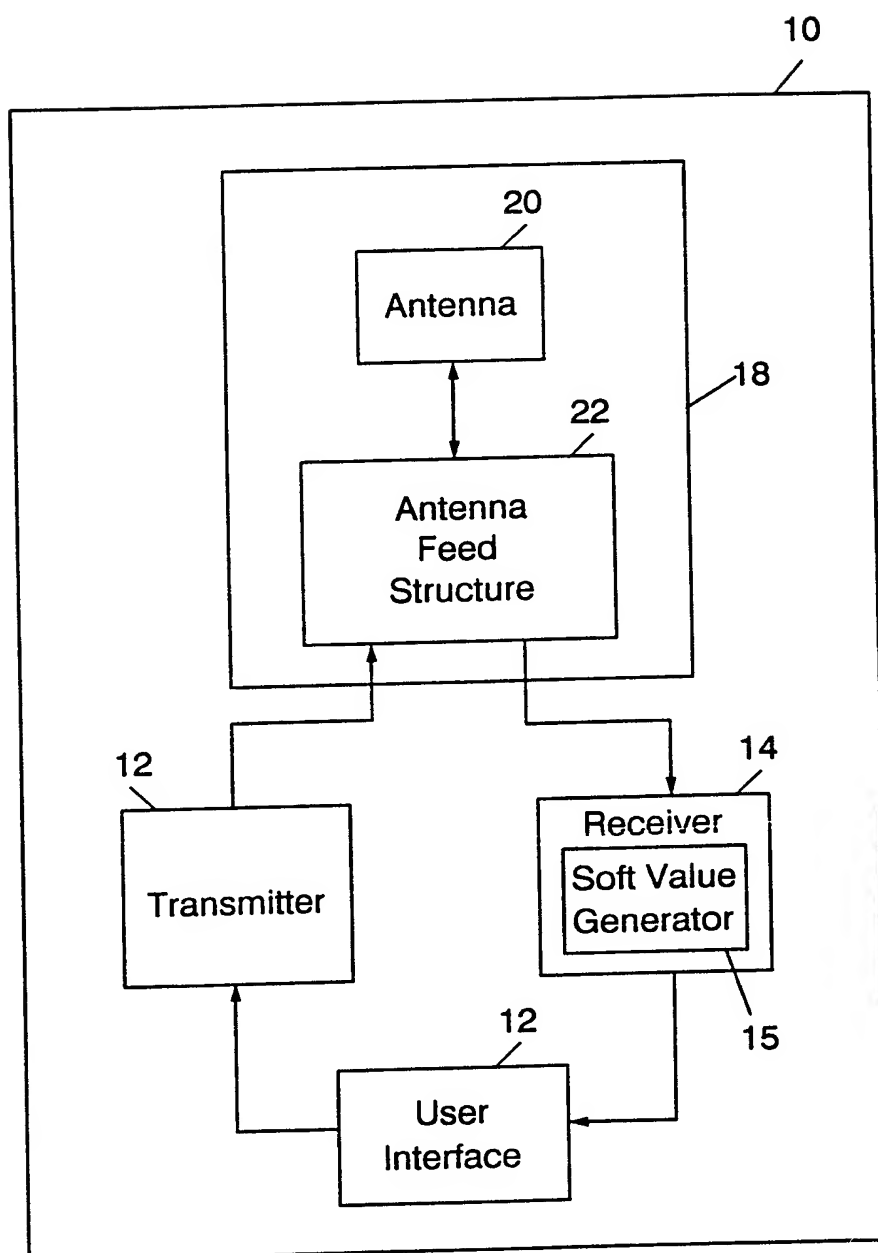


FIG. 4



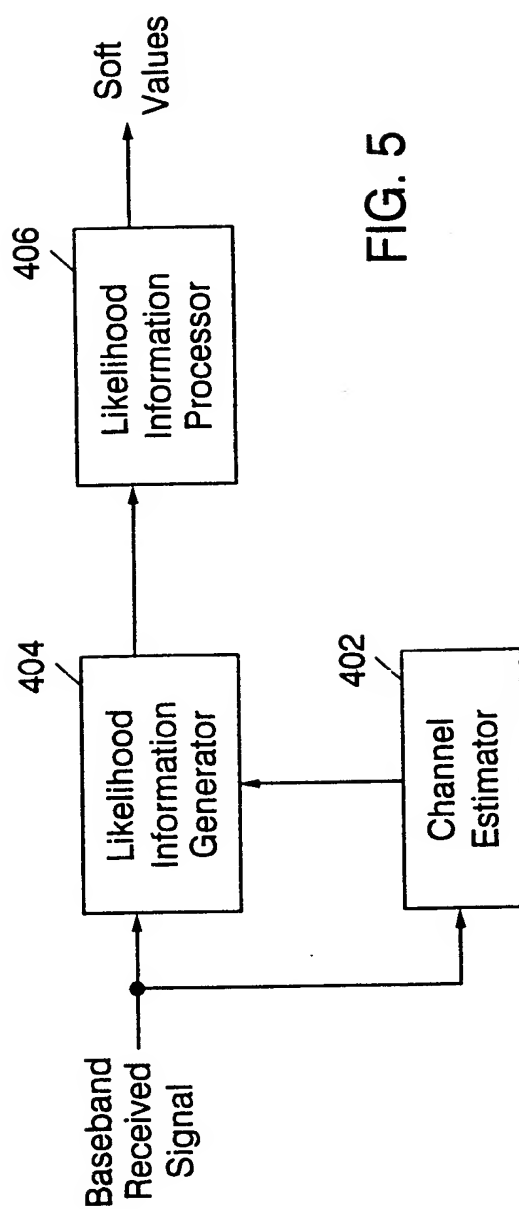
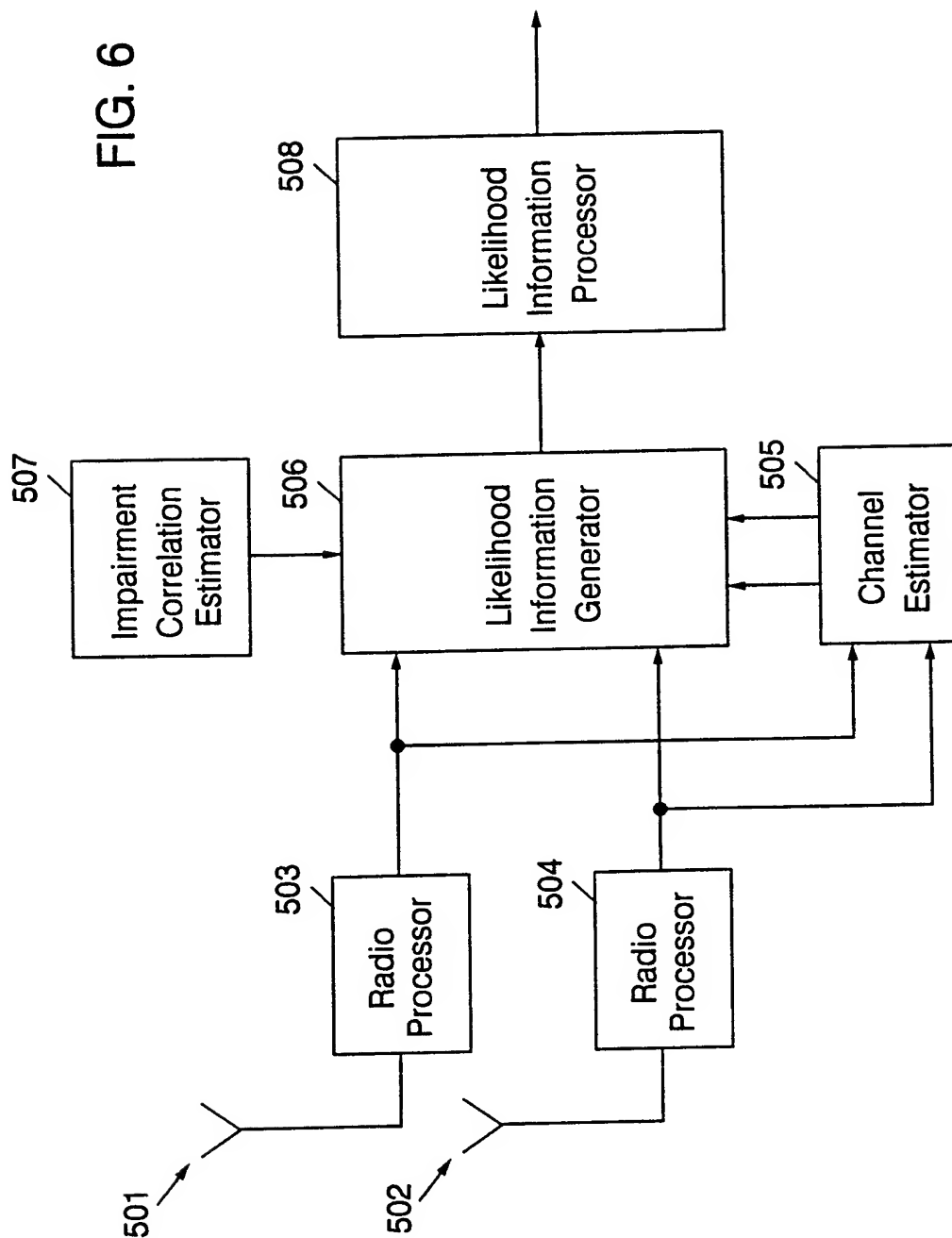


FIG. 5



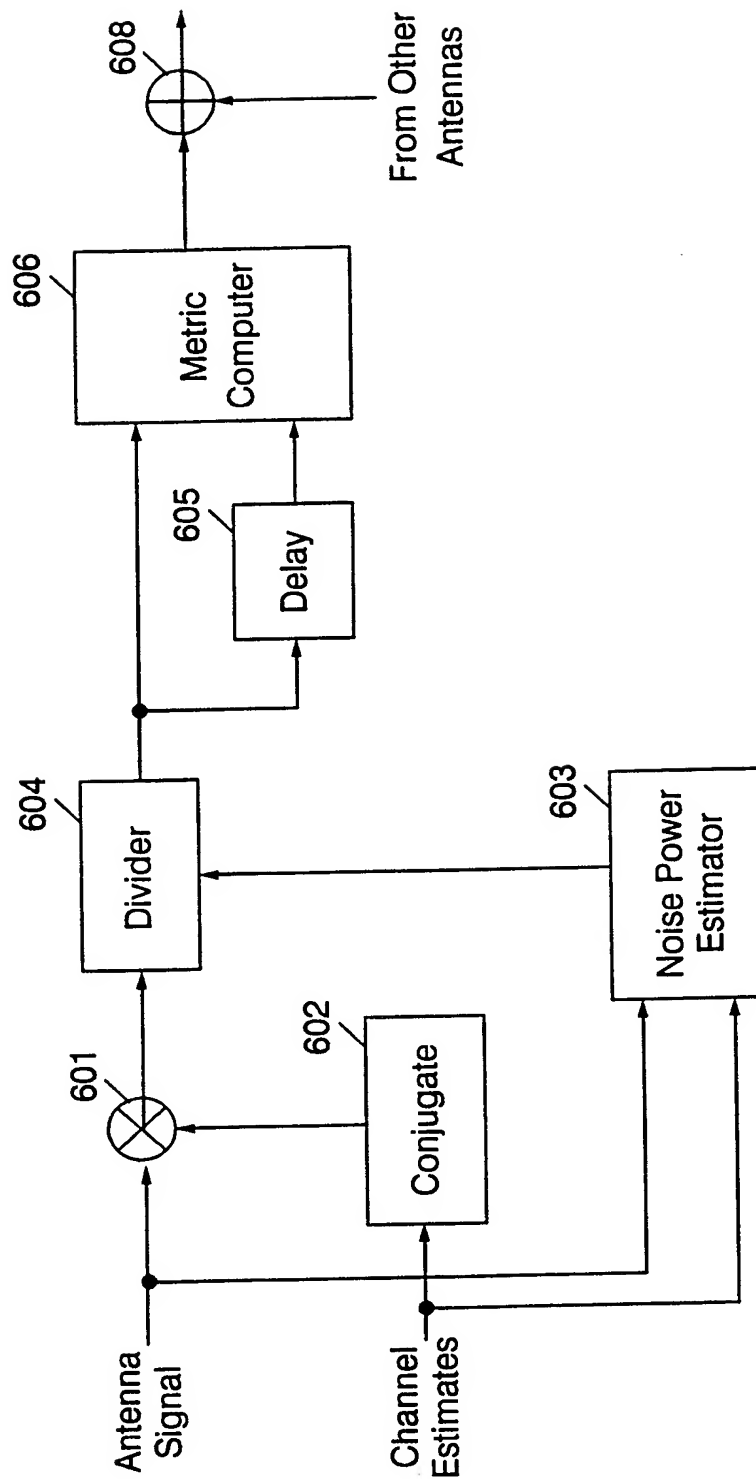
5/9

FIG. 6



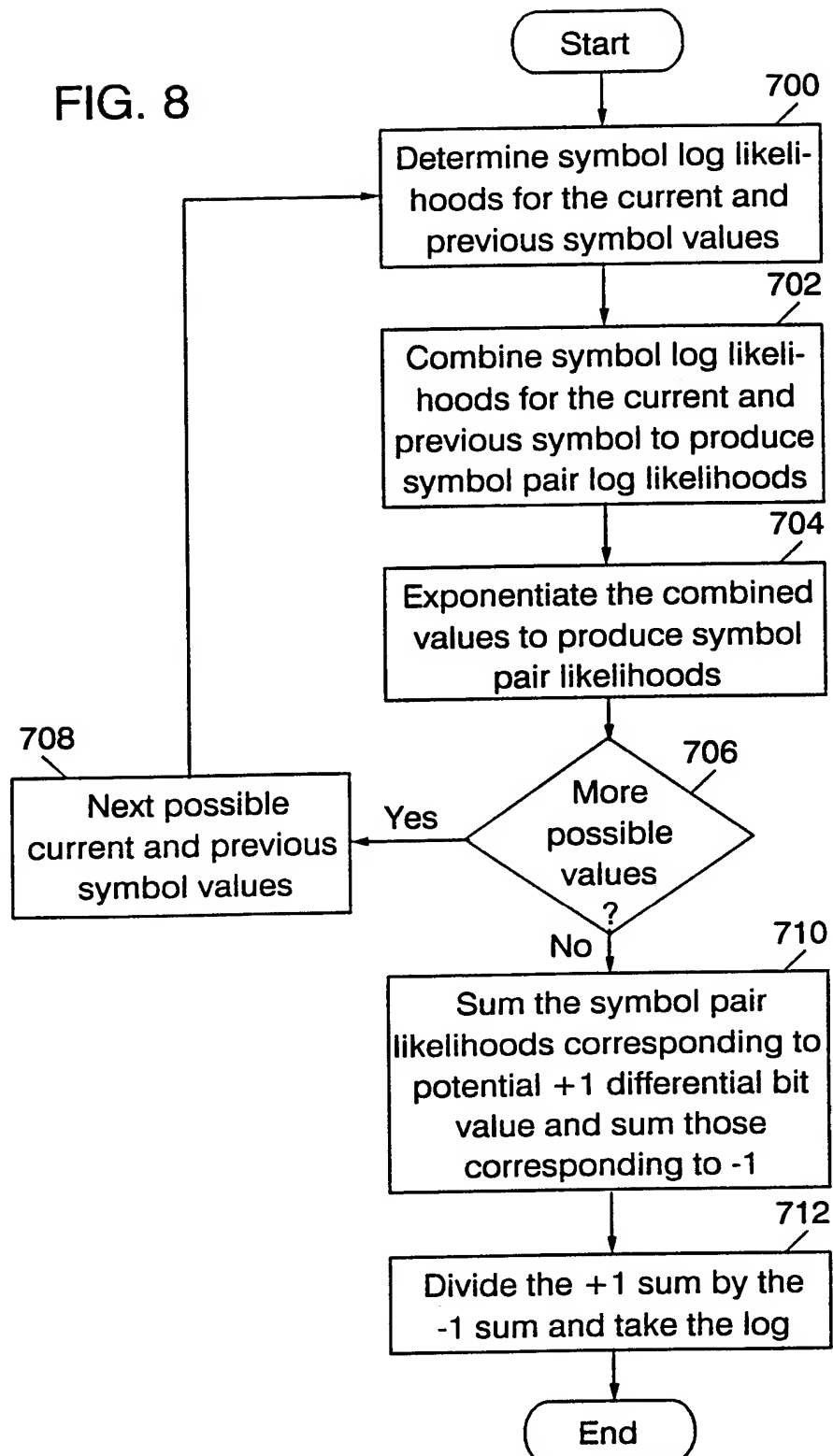
6/9

FIG. 7



7/9

FIG. 8



8/9

FIG. 9

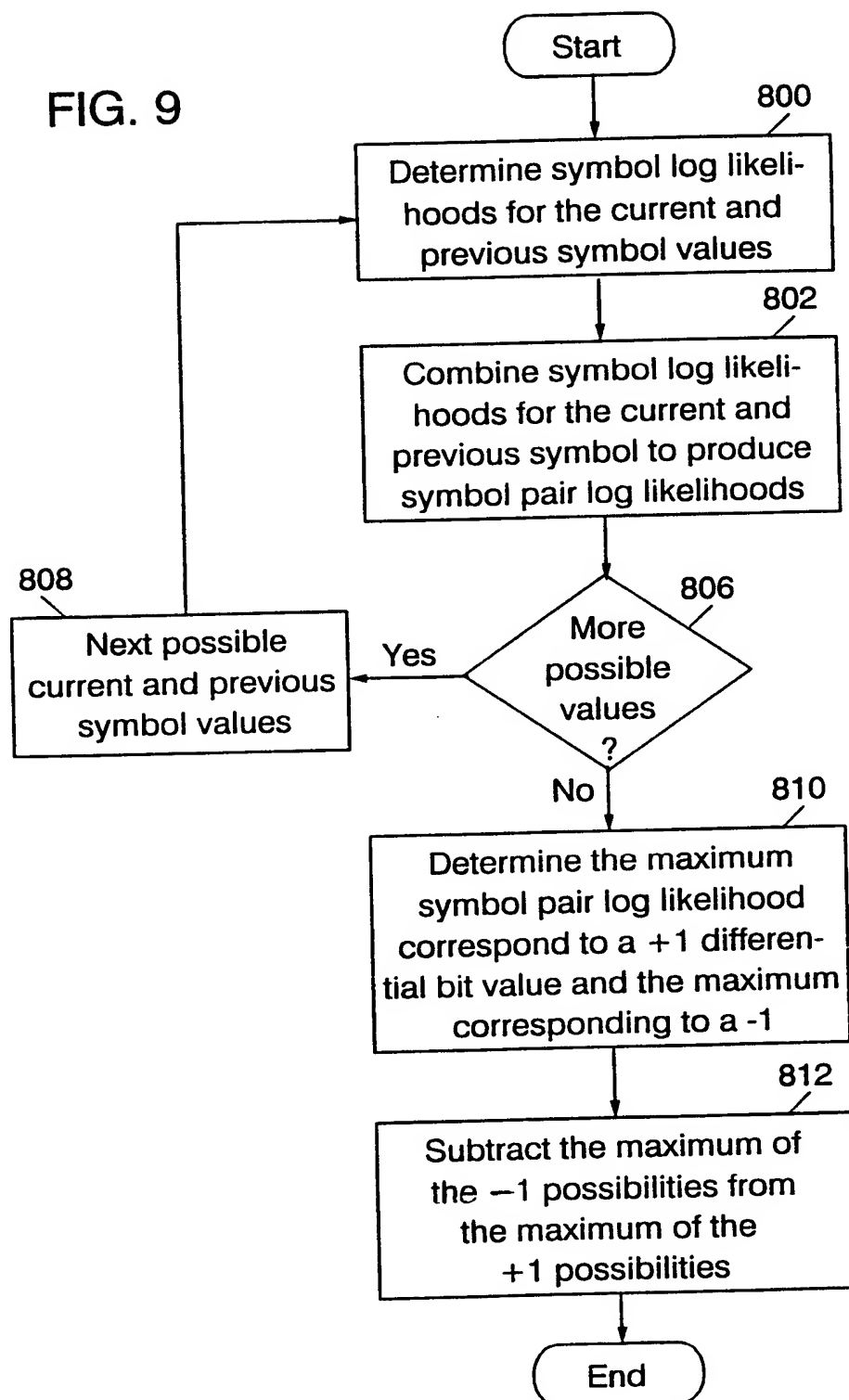
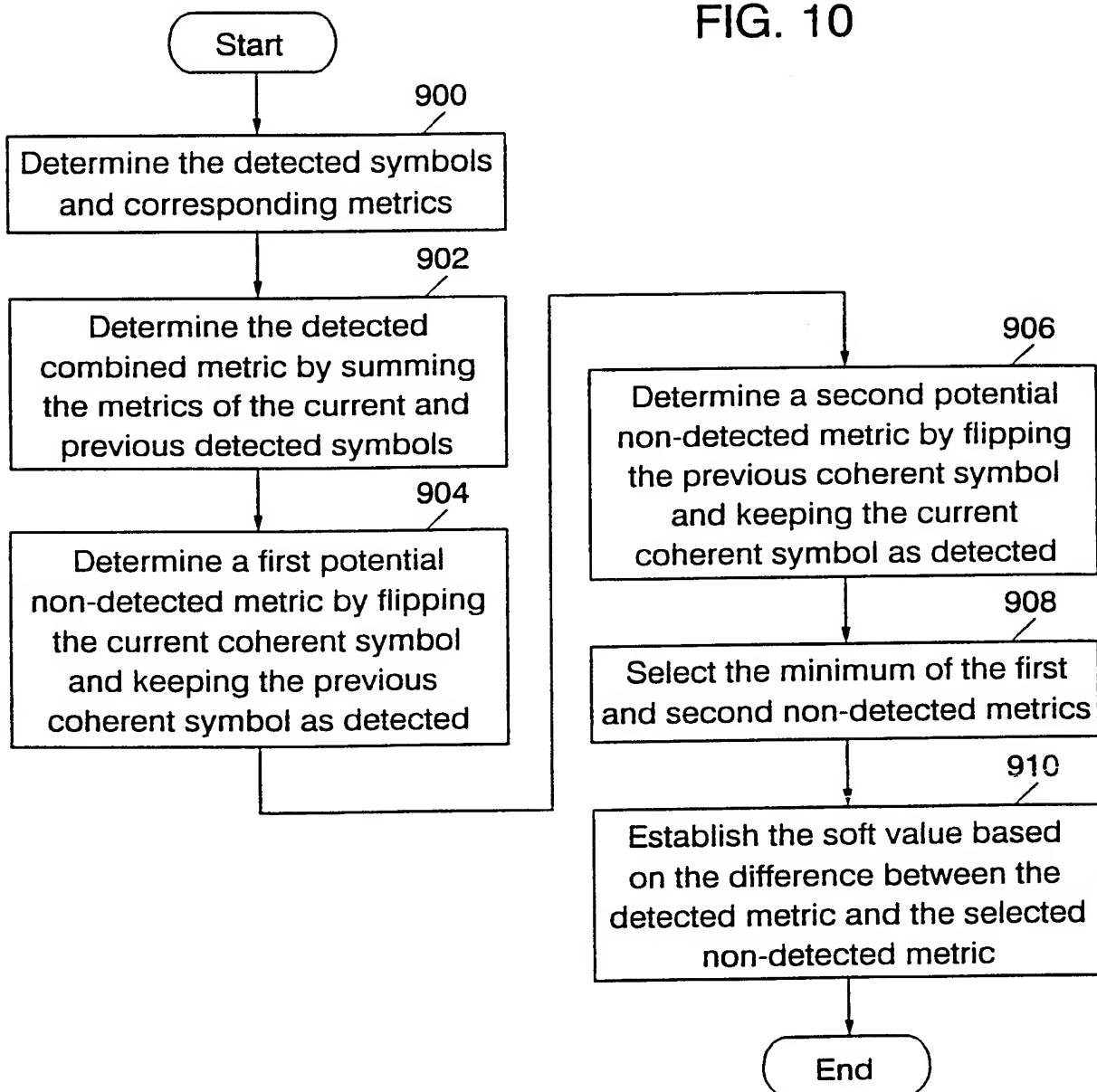


FIG. 10



# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 99/19221

**A. CLASSIFICATION OF SUBJECT MATTER**  
IPC 7 H04L27/227 H04L25/03

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 788 244 A (SONY) 6 August 1997 (1997-08-06)	1,6,7, 9-14, 16-20, 22-27, 29,30, 32-37, 39,44, 45, 47-52, 54-58, 60-65, 67,68, 70-75, 77,78
Y	page 2, line 25 - line 26 page 3, line 27 - line 41 page 6, line 12 - line 31	2-5,8, 15,21,
	-/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

\* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

1 February 2000

Date of mailing of the international search report

08/02/2000

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

Authorized officer

Scriven, P

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 99/19221

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
		28, 31, 38, 40-43, 46, 53, 59, 66, 69, 76
X	<p style="text-align: center;">----</p> <p>EP 0 731 587 A (AT&amp;T) 11 September 1996 (1996-09-11)</p> <p>column 3, line 41 - line 44 column 3, line 51 - line 57</p> <p style="text-align: center;">----</p>	<p>1, 6, 7, 9-14, 16-20, 22-27, 29, 30, 32-37, 39, 44, 45, 47-52, 54-58, 60-65, 67, 68, 70-75, 77, 78</p>
X	<p style="text-align: center;">----</p> <p>EP 0 504 890 A (SONY) 23 September 1992 (1992-09-23)</p> <p>figure 5</p> <p style="text-align: center;">----</p>	<p>1, 6, 7, 9-14, 16-20, 22-27, 29, 30, 32-37, 39, 44, 45, 47-52, 54-58, 60-65, 67, 68, 70-75, 77, 78</p>
Y	<p style="text-align: center;">----</p> <p>US 5 608 763 A (CHIASSON, BAUM) 4 March 1997 (1997-03-04)</p> <p>column 1, line 53 - line 56 column 3, line 21 - line 24 column 4, line 65 - column 5, line 5 column 5, line 26 - line 43</p> <p style="text-align: center;">----</p>	<p>2-5, 15, 28, 38, 40-43, 53, 66, 76</p>
Y	<p style="text-align: center;">----</p> <p>WO 96 10879 A (MOTOROLA) 11 April 1996 (1996-04-11) page 12, line 29 - line 34 page 14, line 16 - line 25 page 16, line 1 - line 6</p> <p style="text-align: center;">----</p>	<p>8, 21, 31, 46, 59, 69</p>
	-/--	

# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 99/19221

## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>WO 98 36580 A (ISRAEL LTD.)  20 August 1998 (1998-08-20)  page 3, line 13 - line 16  page 4, line 3 - line 7  -----</p>	<p>1, 29, 39,  67</p>



# INTERNATIONAL SEARCH REPORT

information on patent family members

International Application No

PCT/US 99/19221

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0788244 A	06-08-1997	GB 2309865 A DE 69700136 D DE 69700136 T JP 9214369 A US 5905764 A	06-08-1997 22-04-1999 23-09-1999 15-08-1997 18-05-1999
EP 0731587 A	11-09-1996	US 5729558 A JP 8321854 A US 5872801 A	17-03-1998 03-12-1996 16-02-1999
EP 0504890 A	23-09-1992	JP 4292043 A JP 4292042 A US 5202643 A	16-10-1992 16-10-1992 13-04-1993
US 5608763 A	04-03-1997	NONE	
WO 9610879 A	11-04-1996	US 5659573 A US 5619524 A BR 9506385 A CA 2176945 A CN 1136378 A EP 0732022 A FI 962326 A IL 114836 A JP 9507014 T PL 314846 A	19-08-1997 08-04-1997 16-09-1997 11-04-1996 20-11-1996 18-09-1996 04-06-1996 27-12-1998 08-07-1997 30-09-1997
WO 9836580 A	20-08-1998	AU 5877298 A EP 0960498 A	08-09-1998 01-12-1999